Environmental Research Section A **80,** 172–179 (1999)
Article ID enrs.1998.3888, available online at http://www.idealibrary.com on IDEAL®

Characteristics of Pesticide Use in a Pesticide Applicator Cohort: The Agricultural Health Study

Michael C. R. Alavanja,*[,1] Dale P. Sandler,† Cheryl J. McDonnell,‡ Charles F. Lynch,§
Margaret Pennybacker,¶ Shelia Hoar Zahm,* David T. Mage,‖ William C. Steen,**
Wendy Wintersteen,†† and Aaron Blair*

**Epidemiology and Biostatistics Program, National Cancer Institute, Bethesda, Maryland Z0892; †Epidemiology Branch, National Institute of Environmental Health Sciences, Research Triangle Park, North Carolina; ‡SRA Technologies, Inc., Falls Church, Virginia; §University of Iowa, Iowa City, Iowa; ¶Battelle/Survey Research Associates, Durham, North Carolina; ‖Environmental Protection Agency at Research Triangle Park, North Corolina; **Environmental Protection Agency in Athens, Georgia; and ††Iowa State University, Ames, Iowa*

Received December 15, 1997

Data on recent and historic pesticide use, pesticide application methods, and farm characteristics were collected from 35,879 restricted-use pesticide applicators in the first 2 years of the Agricultural Health Study, a prospective study of a large cohort of private and commercial licensed pesticide applicators that is being conducted in Iowa and North Carolina. (In Iowa, applicators are actually "certified," while in North Carolina they are "licensed"; for ease of reference the term license will be used for both states in this paper.) Commercial applicators (studied in Iowa only) apply pesticides more days per year than private applicators in either state. When the types of pesticides being used by different groups are compared using the Spearman coefficient of determination (r^2), we find that Iowa private and Iowa commercial applicators tend to use the same type of pesticides ($r^2 = 0.88$). White and nonwhite private applicators tended to use the same type of pesticides (North Carolina $r^2 = 0.89$), as did male and female private applicators (Iowa $r^2 = 0.85$ and North Carolina $r^2 = 0.84$). There was less similarity ($r^2 = 0.50$) between the types of pesticides being used by Iowa and North Carolina private applicators. A greater portion of Iowa private applicators use personal protective equipment than do North Carolina private applicators, and pesticide application methods varied by state. This heterogeneity in potential exposures to pesticides between states should be useful for subsequent epidemiologic analyses using internal comparison groups.

Key Words: **pesticides; occupational exposure; cancers; noncancer toxicity; farmers.**

INTRODUCTION

Specific agricultural agents that might be responsible for the excess risks of cancer of the lip, stomach, brain, prostate, connective tissue, and lymphatic and hematopoietic system among male farmers (Blair *et al.*, 1985, 1993; Pearce and Reif, 1990; Blair and Zahm, 1991) have not been clearly identified, but the strongest link to date is with pesticides. In the few studies focusing on women with pesticide exposure, ovarian cancer has been linked with triazine herbicides (Donna *et al.*, 1989), breast cancer with insecticides (Falck *et al.*, 1992; Wolfe *et al.*, 1993), and multiple myeloma (Zahm and Blair, 1992) and non-Hodgkin's lymphoma (Zahm *et al.*, 1995; Folsom *et al.*, 1996) with various chemicals. Exposure to some pesticides and other agricultural factors may also be associated with acute and chronic effects on the nervous, renal, respiratory, and reproductive systems of men and women (Greaves, 1992; Baker and Wilkeson, 1990). However, much of the evidence for these effects comes from case reports and experimental animal studies, so epidemiologic studies are needed to derive etiologic conclusions.

Accurate assessment of historical exposures is difficult in all epidemiologic investigations. Problems

This work was supported by Contracts N01-CP-33047, N01-CP-33048, and N01-CP-21095 and was conducted in accordance with national and institutional guidelines for the protection of human subjects.

[1]To whom reprint requests should be addressed at Epidemiology and Biostatistics Program, National Cancer Institute, EPN/543, 6130 Executive Blvd., Bethesda, MD 20892. Fax: 301/402-3256. E-mail alavanjam@epndce.nci.nih.gov.

0013-9351/99 $30.00

in recalling past agricultural exposures and the possibility of case-recall bias is a concern in retrospective studies. In prospective studies, the case-recall bias is eliminated (although nondifferential misclassification may still occur) and exposure assessment is improved because of the opportunity to obtain information periodically. Many factors may influence exposure. This paper describes exposure patterns by host and farm characteristics to provide an understanding of exposure patterns and to provide information to help develop survey instruments for future interviews in this and other agricultural populations.

METHODS

A complete discussion of methods used in the Agricultural Health Study has been reported elsewhere (Alavanja *et al.*, 1996; submitted for publication). This project is being conducted in North Carolina and Iowa among registered pesticide applicators and spouses of private applicators. All persons who wish to apply restricted-use pesticides in these states must obtain a pesticide applicators' license through their state Department of Agriculture. At the licensing facility, each pesticide applicator is asked to complete a 21-page, optically scannable enrollment questionnaire. In Iowa, private (99% farmers) and commercial pesticide applicators (i.e., individuals employed by agricultural dealerships, pest control companies, or by other businesses who use restricted-use pesticides) obtain licenses at the same facilities and are therefore enrolled together. In North Carolina, private and commercial pesticide applicators are licensed at separate facilities; only private applicators (91% farmers; the remainder primarily perform applications to lawn and garden) from North Carolina were enrolled.

Information from the enrollment questionnaire was used to assess pesticide-related employment (farm vs nonfarm), farm characteristics (such as farm size, type of crops grown, and livestock raised), types of pesticides used, application methods employed, and type of protective equipment used, and differences in exposure by state and license type were determined. For 22 pesticides that have widespread use in either Iowa or North Carolina, the rank order by the percentage of the population using the chemical last year was determined. The ranking was done separately for Iowa farmers, Iowa commercial applicators, and North Carolina farmers who enrolled during the first 2 years of the study. The Spearman coefficient of determination was computed to quantify the similarity of pesticide use in the three state/license categories (SAS Institute, 1993).

RESULTS

A total of 35,879 pesticide applicators completed the enrollment questionnaire of 51,256 applicators who sought restricted-use pesticide licenses in 1994 and 1995 (Table 1). In Iowa, 16,193 private applicators and 4897 commercial applicators enrolled in the study, while in North Carolina 14,789 private applicators enrolled. Currently, about 3% of the applicators enrolled in the study are women and 3.1% are minorities.

Farms in Iowa (median farm size–306 acres) are larger than farms in North Carolina (median farm

TABLE 1
Number and Percentage of Applicators Enrolled in the Agricultural Health Study by State, License Type, Gender, and Race

	Applicators							
	Iowa private		NC private		Iowa commercial		Total	
Gender								
Male	15,365	98.6%	13,556	95.5%	4442	96.1%	33,363	97.0%
Female	215	1.4%	641	4.5%	178	3.9%	1,034	3.0%
Unknown[a]	613		592		277		1,482	
Race								
White	14,951	99.9%	12,609	92.7%	4596	99.5%	32,156	96.9%
Black	11	0.1%	814	6.0%	6	0.1%	831	2.5%
Others	11	0.1%	176	1.3%	19	0.4%	206	0.6%
Unknown[a]	1,220		1,190		276		2,686	
Total	16,193		14,789		4897		35,879	

[a]Follow-up interviews are in progress to fill in missing data.

size–85 acres). Nearly 50% of the farmers in Iowa have operations of over 500 acres, while only 20% of North Carolina farms were that large. The major crops for Iowa farmers in our study are field corn (85.7%), soybeans (78.7%), oats (30.8%), hay (39.2%), and alfalfa (32.3%). North Carolina farms are more diverse. Although field corn (35.0%) and soybeans (36.4%) are important crops in North Carolina as well, tobacco (37.4%), wheat (23.4%), peanuts (10.5%), cotton (10.4%), and sweet corn (10.4%) are also important agricultural commodities. More farmers in Iowa raised hogs and beef than did those in North Carolina (hogs—46.7% versus 8.7%; beef—42.4% versus 22.9%, respectively), while poultry farming is more common in North Carolina (5.4%) than in Iowa (2.6%).

Table 2 ranks pesticides by percentage of applicators using the product in the year previous to enrollment in the study. Herbicides comprise 8, of the 10 pesticides used by the largest number of Iowa farmers, 9 of the 10 used by the largest number of Iowa commercial applicators, and 6 of the 10 used by the largest number of North Carolina farmers. The herbicide glyphosate was used by more than 30% of all three groups. Other herbicides, such as 2,4-D, imazethapyr, atrazine, dicamba, metolachlor, and trifluralin were used by 20–40% of Iowa farmers and commercial applicators, but by only 4 to 15% of North Carolina farmers. Chlorpyrifos is the most widely used insecticide in both Iowa and North Carolina. Fumigants (e.g., methyl bromide) and fungicides (e.g., chlorothalonil) are used more extensively in North Carolina than in Iowa. The median days of application for an average year for commercial applicators in Iowa was 43 days, while the median number of days was 13 for private applicators in Iowa and 12 days for private applicators in North Carolina. Private applicators in Iowa have been applying pesticides for more years (median years–15) than North Carolina applicators (14 years) and commercial applicators in Iowa (7 years).

In Table 3 the percentage of farms using a pesticide was rank ordered for the commodities reported by Iowa and North Carolina farmers as most

TABLE 2

Pesticides Used and Median Number of Applications Made "Last Year"[a] by State and License Type

		Percentage of Population Using Indicated Pesticide Last Year		
Chemical	Type of pesticide[b]	Iowa private	NC private (rank)	Iowa commercial (rank)
2,4-D	H	35.3 (1)	15.5 (2)	36.5 (2)
Glyphosate	H	33.6 (2)	31.5 (1)	40.8 (1)
Imazethapyr	H	32.1 (3)	2.6 (15)	24.6 (4)
Atrazine	H	29.9 (4)	14.0 (3)	23.8 (5)
Dicamba	H	22.4 (5)	4.1 (12)	28.4 (3)
Metolachlor	H	19.6 (6)	8.8 (6)	23.1 (6)
Trifluralin	H	18.6 (7)	5.8 (11)	20.0 (7)
Chlorpyrifos	I	13.6 (8)	12.9 (4)	13.8 (10)
Cyanazine	H	13.0 (9)	2.8 (14)	19.5 (8)
Terbufos	I	13.0 (10)	7.0 (9)	6.1 (13)
Alachlor	H	9.9 (11)	7.1 (8)	16.3 (9)
Permethrin (*Animal*)	I	5.4 (12)	1.4 (19)	2.5 (17)
Fonofos	I	5.1 (13)	1.4 (18)	3.7 (16)
EPTC	H	3.4 (14)	0.5 (21)	11.3 (11)
Captan	FG	2.9 (15)	3.6 (13)	1.8 (19)
Dichlorvos	I	2.8 (16)	0.7 (20)	1.6 (20)
Permethrin (*Crop*)	I	2.3 (17)	5.9 (10)	10.4 (12)
Coumaphos	I	2.1 (18)	2.6 (17)	0.9 (21)
Carbofuran	I	1.2 (19)	2.6 (16)	4.1 (15)
Chlorothalonil	FG	0.4 (20)	7.5 (7)	4.3 (14)
Methyl Bromide	FM	0.1 (21)	10.0 (5)	0.8 (22)
Trichlorfon	I	0.1 (22)	0.2 (22)	2.4 (18)
Mean No. Days Pesticides Applied		17	26	45
Median No. of Days Pesticides Applied		13	12	43
Median No. of Years Pesticides Applied		15	14	7

[a]Last year—year prior to questionnaire adminstration (1993 and 1994); little dierence was found between the two-years.
[b]H, herbicide; I, insecticide; FG, fungicide; FM, fumigant.

TABLE 3
Top Five Chemicals by Major Commodity Raised[a] on the Farm

Commodity (percentge of farms with commodity)	Chemical		Percentage of farms
Grains[b] (64.3%)	Glyphosate	(H)	67.7
	2,4-D	(H)	63.7
	Atrazine	(H)	58.5
	Alachlor	(H)	43.9
	Trifluralin	(H)	42.4
Vegetables[c] (60.1%)	2,4-D	(H)	76.7
	Glyphosate	(H)	74.4
	Atrazine	(H)	73.2
	Alachlor	(H)	57.2
	Trifluralin	(H)	56.2
Fruits[d] (6.4%)	Glyphosate	(H)	78.5
	2,4-D	(H)	62.8
	Atrazine	(H)	53.2
	Chlorpyrifos	(I)	43.5
	Alachlor	(H)	42.1
Christmas trees (3.0%)	Glyphosate	(H)	92.2
	2,4-D	(H)	42.4
	Brom-O-Gas	(FM)	35.7
	Chlorpyrifos	(I)	35.2
	Atrazine	(H)	34.5
Tobacco (15.4%)	Glyphosate	(H)	76.6
	Brom-O-Gas	(FM)	60.0
	Atrazine	(H)	56.3
	2,4-D	(H)	54.7
	Alachlor	(H)	46.0
Cotton (4.3%)	Glyphosate	(H)	84.3
	Atrazine	(H)	68.6
	Matolachlor	(H)	66.4
	Alachlor	(H)	66.2
	2,4-D	(H)	63.0
Peanuts (4.3%)	Glyphosate	(H)	80.5
	Metolachlor	(H)	79.7
	Chlorothalonil	(FG)	77.5
	Alachlor	(H)	73.6
	Atrazine	(H)	72.0

Note. H, herbicide; I, insecticide; FG, fungicide; FM, fumigant.
[a]Percentage of farms growing multiple commodities.
[b]Grains defined as popcorn, field corn, sweet corn, hay, oats, wheat, sorghum, other grains.
[c]Vegetables defined as alfalfa, cabbage, cucumbers, green peppers, potatoes, snapbeans, soybeans, sweet potatoes, tomatoes, other vegetables.
[d]Fruits defined as apples, blueberries, grapes, strawberries, watermelon, other fruit.

frequently raised. The majority of farmers raise multiple crops; therefore, the reported pesticide use does not correlate directly with specific commodities raised. Herbicides are reported by most farmers regardless of commodity. Chlorpyrifos, an insecticide, is widely used by those growing fruit and those growing Christams trees. Fumigants such as methyl bromide are frequently used by tobacco farmers and by those who raise Christams trees. A majority of peanut farmers reported using the fungicide chlorothalonil. Herbicides are the most frequently reported chemicals among farmers who raise livestock (glyphosate, 67.8%; 2,4-D, 63.8%; atrazine, 58.5%; alachlor, 44.0%; trifluralin, 42.4%, not shown in table) presumably because most farmers who raise livestock also grow a number of crops (corn, alfalfa, soybeans, and hay) that require the use of herbicides.

We compared pesticide use for several different groups defined by state, pesticide license type, gender, and race (Table 4). The Spearman (i.e., rank order) coefficient of determination shows that the relative frequency of specific pesticide use is very similar for Iowa farmers and Iowa commercial applicators ($r^2 = 0.88$). Within the same state there was also a high correlation between pesticide usage between males and females (in Iowa $r^2 = 0.85$ and in North Carolina $r^2 = 0.84$) and between white and nonwhite farmers in North Carolina ($r^2 = 0.89$). Too few minority farmers exist in Iowa to make a comparison by race. A much lower correlation was seen between private applicators in Iowa and North Carolina ($r^2 = 0.50$).

The number of different pesticides used in the year prior to enrollment is shown in Fig. 1 by farm size. The number of different pesticides used increases as the size of the farm increases. For farms over 500 acres, an average of 3.1–3.5 different pesticides were used in the last year (mean = 3.3); for farms between 200 and 499 acres, 2.6–2.7 different

TABLE 4
Rank Order Correlation of 22 Pesticides Used Last Year by State and License Type

Question addressed	Coefficient of determination (r^2)
1. Were similar pesticides applied by white and nonwhite farmers in North Carolina last year?	0.89
2. Were similar pesticides applied by Iowa farmers and Iowa commerical pesticide applicators last year?	0.88
3. Were similar pesticides applied by male and female farmers in Iowa last year?	0.85
4. Were similar pesticides applied by male and female farmers in North Carolina last year?	0.84
5. Were similar pesticides applied by Iowa farmers and North Carolina farmers last year?	0.50

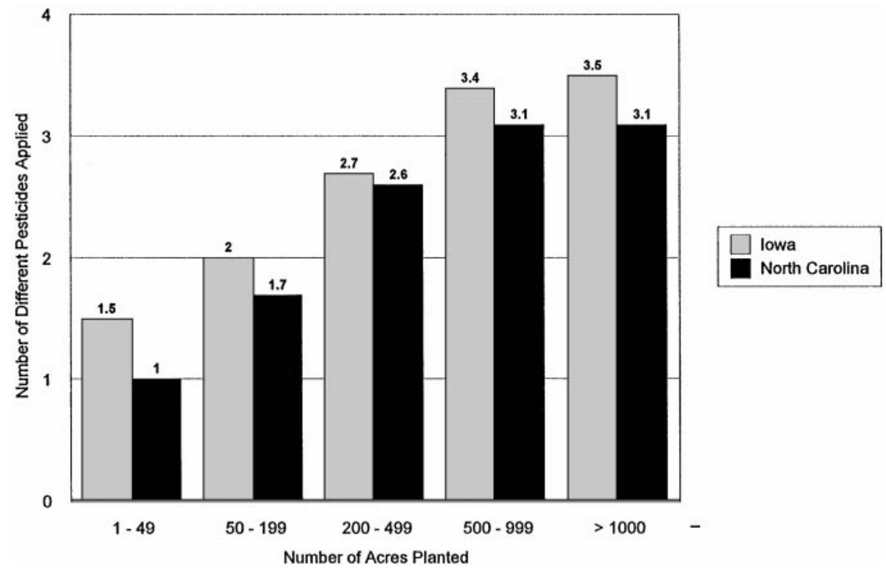

FIG. 1. Average number of different pesticides used last year by number of acres planted in Iowa and North Carolina.

pesticides were used on average (mean = 2.6), while on farms less than 199 acres 1–2 different pest-icides were used on average (mean = 1.4). North Carolina farmers used, on average, slightly fewer pesticides than Iowa farmers in each category of farm size in the year prior to enrollment.

The mean number of days of pesticide application increases with size of the farm, varying from 4 to 17 days for farms less than 50 acres to 44 to 51 days for farms over 1000 acres (Fig. 2). In general, when the size of the farm is held constant, North Carolina farmers spend more days applying pesticides than Iowa farmers. For Iowa farms of less than 5 acres an unusually high average number of days are spent applying pesticides. Preliminary analysis suggests that this may be due to occupational history; the private applicators may also apply pesticides in a part time job.

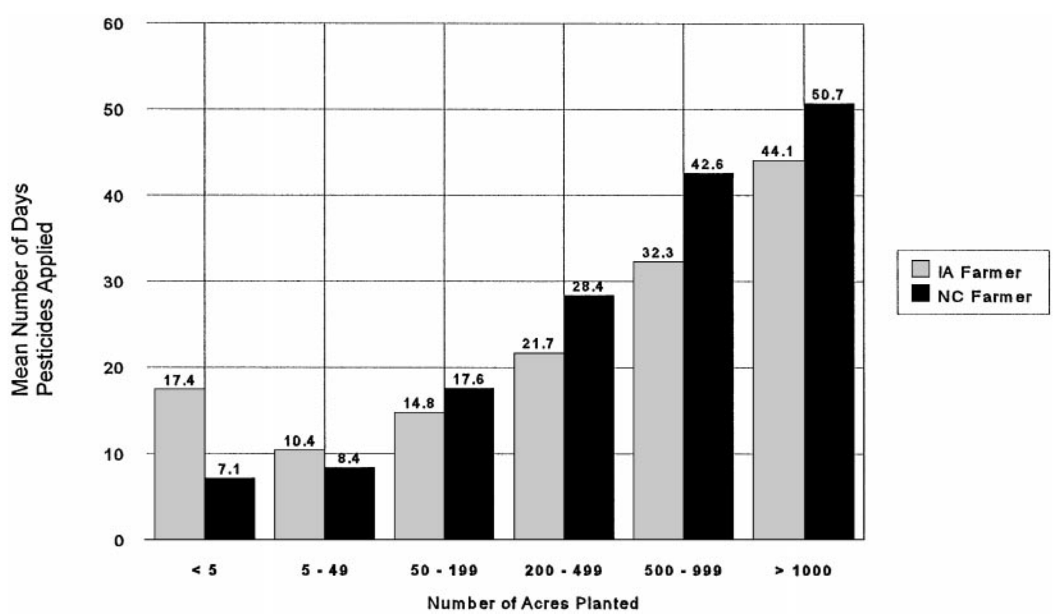

FIG. 2. Average number of days pesticides were applied last year by number of acres planted in Iowa and North Carolina.

TABLE 5
Percentage of Frequency of Pesticide Application Equipment Ever Used by State and License Type

Application	IA farmer	NC farmer	IA commerical
Boom on tractor, truck, or trailer	71.4	62.1	51.5
Hand spray gun	61.4	48.4	55.5
In furrow or banded	57.9	24.3	3.1
Spray animals	46.0	19.3	15.4
Inject animals	32.2	13.4	9.3
Dust animals/pour on animals	30.1	22.1	10.7
Seed treatment	24.6	18.3	8.9
Ear tags	23.9	10.1	7.7
Backpack sprayer	16.6	32.1	26.6
Dip animals	13.6	12.2	7.3
Powder duster	8.2	18.0	7.7
Distribute tablets/granules	6.3	8.3	12.4
Mist blower/fogger	6.0	5.8	6.9
Pour fumigant from bucket	1.8	18.0	7.7
Gas canister	1.6	11.7	2.4
Aerial (*aircraft application*)	1.4	1.4	0.8
Air blast	0.6	2.6	1.8
Row fumigation	0.6	13.6	0.3
Do not personally apply pesticides	6.0	5.4	3.3
None of these	0.6	1.1	2.3
Other	0.3	0.3	2.0

The frequency of use of different pesticide application equipment is shown in Table 5 for Iowa famers, Iowa commercial applicators, and North Carolina farmers. Boom-type applications and handgun spraying are common techniques used by every category of applicator, while the air blast method and aerial spraying are uncommon in every category. Other techniques vary greatly by state or license type. Backpack spraying, row fumigation, the use of gas canisters, and pouring fumigants from buckets are much more common in North Carolina, while applying in furrow or banding, spraying, injecting, using ear tags, and dusting or pouring insecticides on animals is much more common in Iowa.

The use of protective equipment by state and license type is shown in Table 6. Of the farmers responding in North Carolina, 15.6% reported that they never use protective equipment, compared to 4.2% of the farmers and 3.2% of the commercial applicators in Iowa. The use of cartridge respirators is reported more frequently in North Carolina and for Iowa commercial applicators, compared to Iowa farmers, who rarely apply pesticides requiring cartridge respirators. Chemical, resistant gloves are used by 76% of the famers and 73.3% of the commercial applicators in Iowa, but by only 39.4% of the farmers in North Carolina. Although not recommended because of contamination concerns, fabric or leather gloves are used by 20.2% of the North Carolina private applicators but only by 13.6% of the Iowa farmers and 10% of the commercial applicators in Iowa.

DISCUSSION

While nearly all study subjects in the Agricultural Health Study have a history of extensive pesticide use, other determinants of pesticide exposure vary considerably by license category (e.g., private versus commercial). The frequency of pesticide application by commercial pesticide applicators varies greatly, but on average commercial applicators apply pesticides more frequently but have not been engaged in such work as long as private applicators. The types of pesticides used vary by state. Iowa farmers primarily use herbicides and insecticides but relatively few fungicides and fumigants. In North Carolina, farmers use many of the pesticides commonly used in Iowa, but they also use more fungicides and fumigants. In addition to corn and soybeans, which are grown in both states, North Carolina farmers raise tobacco, fruit and vegetables, cotton and peanuts. A larger proportion of Iowa farmers have livestock than North Carolina famers.

While there are substantial differences between states in the types of pesticides used, there is little difference within a state. In Iowa, commercial and private applicators used similar pesticides. Similarly, within a state, differences between the pesticides used by male and female applicators or between white and nonwhite applicators tend to be

TABLE 6
Percentage of Frequency of Personal Protective Equipment Used by State and License Type

Protective equipment	IA farmer	NC farmer	IA commerical
Chemical resistant gloves (for example, neoprene or nitrile gloves)	76.0	39.4	73.3
Face shields or goggles	47.0	33.2	44.8
Other protective clothing (boots, apron, waterproof pants)	29.8	26.5	41.7
Fabric/leather gloves	13.6	20.2	10.0
Disposable outer clothing (like Tyvek)	8.6	9.2	18.4
Cartridge respirator or gas mask	8.3	18.2	14.0
Never use protective equipment[a]	4.2	15.6	3.2
Do not personally handle pesticides	4.1	5.0	10.1

[a]It is noted that applicators may not always be following manufacture's label instructions.

small. Farmers in Iowa and North Carolina generally grow multiple commodities; we did not obtain information on pesticide use by commodity. However, use of specific chemicals is more strongly associated with certain commodities. Several herbicides, including glyphosate, 2,4-D, atrazine, alachlor, and trifluralin were common to many different kinds of farm operations, but insecticides, fungicides, and fumigants tended to be more closely associated with specific farm operations.

Despite our concerns about multiple chemical exposures and potential reporting difficulties, questionnaire responses are generally complete and interviewers report applicators have relatively little difficulty completing the pesticide section of the questionnaire. There is some specificity and diversity of pesticide application by crop, which provides additional reassurance. The average number of different pesticides used increased with farm size and, as expected, the number of days pesticides were applied also increased as the size of the farm increased. These differences in pesticide exposure patterns (e.g., those using and those not using specific chemicals) by state and type of farm operation will facilitate the ability to make internal comparisons in subsequent epidemiologic analyses.

Different practices of personal protective equipment use and application methods also influence exposure to pesticides. Again, substantial differences were observed between Iowa and North Carolina applicators for both determinants of exposure. Using hand-held application equipment is more liable to result in exposure than other application methods (Lavy *et al.*, 1987; Libich *et al.*, 1984). Several of these techniques, including row fumigation, pouring fumigants from buckets, the use of backpack sprayers, and the use of gas canisters, are employed more frequently by North Carolina farmers. Dusting or spraying livestock with insecticide, a technique also associated with relatively high exposures (PHED, 1995), is more common in Iowa. These techniques are typically used with different chemicals.

A substantially larger fraction of North Carolina farmers do not use any personal protective equipment when applying pesticides than either Iowa farmers or commercial applicators. While the proper use of chemical-resistant gloves has been demonstrated to significantly reduce the dermal exposure to pesticides (PHED, 1995) and the use of face shields and goggles has been shown to reduce eye exposure (PHED, 1995), many more Iowa applicators use these items of equipment than North Carolina farmers. North Carolina farmers, who are more apt to apply chemical fumigant, reported higher aggregate usage of cartridge respirators or gas masks, which are required equipment. These masks, however, are used by only a small portion of the applicators in either state.

In summary, study subjects in the Agricultural Health Study generally have made many pesticide applications per year but only a relatively small number of different pesticides are used by pesticide applicators in 1 year. While the herbicide glyphosate is used widely in each state, other pesticides differ significantly in use by state and crop type. Other determinants of exposure also vary considerably by state and license type, suggesting that epidemiologic analysis based on internal comparisons will be possible.

ACKNOWLEDGMENTS

The authors extend thanks to Nyla Logsden-Sackett (Study Coordinator of the Iowa Field Station), Joy Pierce (Study Coordinator of the North Carolina Field Station), the North Carolina Cooperative Extension Service, the Iowa State University Extension Service, the Iowa Department of Agriculture and Land Stewardship, and the University of Iowa Center for Health Effects of Environmental Contamination for their assistance in enrolling certified pesticide applicators into the Agricultural Health Study.

REFERENCES

Alavanja, M. C. R., Sandler, D. P., McDonnell, C. J., Lynch, C. F., Pennybacker, M., Zahm, S. H., Mage, D., Steen, W., and Blair, A. (1998). Factors associated with pesticide induced visits to health care facilities in the Agricultural Health Study. *Environ. Health Perspect.* **106,** 415–420.

Alavanja, M. C. R., Sandler, D. P., McMaster, S. B., McDonnell, C. J., Lynch, C. F., Pennybacker, M., Zahm, S. H., Rothman, N., Dosemeci, M., Bond, A. E., and Blair, A. (1996). The agricultural health study. *Environ. Health Perspect.* **104,** 362–369.

Nigg, H. N., Beir, R. C., Carter, O., Chaisson, C., Franklin, C., Lavy, T., Lewis, R. G., Lombardo, P., MaCarthy, J. F., Maddy, K. T., Moses, M., Norris, D., Pexk, C., Skinner, K., and Tariff, R. G. (1990). The effects of pesticides on human health: Exposure to pesticides. *In* "Advances in Modern Environmental Toxicology" S. R. Baker, and C. F. Wilkeson, Eds.), Vol. XVIII, pp. 35–130, Princeton Sci. Publ. Princeton, New Jersey.

Blair, A., Dosemeci, M., and Heineman, E. F. (1993). Cancer and other causes of death among male and female farmers from twenty-three states. *Am. J. Ind. Med.* **23,** 729–742.

Blair, A., Malker H., and Cantor K. P. (1985). Cancer among farmers—A review. *Scand. J. Work Environ. Health* **11,** 397–407.

Blair, A., and Zahm, S. H. (1991). Cancer among farmers. *In* "Occupational Medicine: State of the Art Reviews" (D. H. Cordes and D. F. Rea, Eds.), pp. 335–354. Hanley and Belfus, Helsinki, Finland.

Pearce N., Reif J. S. (1990). Epidemiologic studies of cancer in agricultural workers. Am *J. Ind. Med.* **18,** 133–142.

Donna, A., Crosignani P., and Robutti, F. (1989). Triazine herbicides and ovarian epithelial neoplasms. *Scan. J. Work. Environ. Health* **15,** 47–53.

Falck, F., River, A., Wolff, M. S. and Gobolds, S. (1992). Pesticides and polychlorinated biphenyl residues in human breast lipids and their relationship to breast cancer. *Arch. Environ. Health* **47,** 143–146.

Folsom, A. R., Zhang, S., Sellers, T. A., Zheng, W., Kushi, L. H., and Cerhan, J. R. (1996). Cancer incidence among women living on farms: Findings from the Iowa Women's Health Study. *J. Occup. Environ. Med.* **38,** 1171–1176.

Greaves, I. A. (1992). Agricultural Health: Exposure to toxic substances. *Health Environ. Digest* **4,** 1–4.

Lavy, T. L., Norris, L. A., Mattice, J. D., and Marks, D. B. (1987). Exposures of forestry groundworkers to 2,4-D, picloram and dichlorprop. *Environ. Toxical. Chem.* **6,** 209–224.

Libich, S., To, J., Frank, R., and Sironi, G. J. (1984). Occupational exposures of herbicide applicators to herbicides used along electric power transmission line right-of-ways. *Am Ind. Hyg. Assoc. J.* **45** (1) 56–62.

PHED, (1995). The Pesticide Handlers Exposure Database, "Reference Manual Version 1.1, The PHED Task Force representing Health Canada," The U.S. EPA, and the American Crop Protection Association, Versar, Springfield.

SAS Institute. (1993). "SAS/STAT User's Guide," release 6.09. SAS Inst., Cary, North Carolina.

Wolfe, J. S., Toniolo, P. G., Lee, L. W., Rivera, M., and Dubin, H. (1993). Blood of levels of organochlorine residuals and the risk of breast cancer. *J. Natl. Cancer Inst.* **85,** 648–652.

Zahm, S. H., and Blair, A., (1992). Sex differences in the risk of multiple myeloma associated with agriculture. *Br. J. Ind. Med.* **49,** 815–816.

Zahm, S. H., Weisenberger, D. D., Saal, R. C., Vaught, J. B., Babbitt, P. A., and Blair, A. (1995). Pesticide use, genetic susceptibility, and non-Hodgkin's lymphoma in women, *In* "Third International Symposium: Issues in Health, Safety, and Agriculture" (H. M. McDufie, J. A. Dosman, K. M. Semchuk, and S. A. Okenchock, Eds.), pp. 127–134, Lewis, Michigan.